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Source parameters of small and moderate earthquakes in the area of the 2009 L'Aquila earthquake sequence (central Italy)

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ABSTRACT

The main goal of this study is to provide moment tensor solutions for small and moderate earthquakes of the 2009 L'Aquila seismic sequence (central Italy). The analysis was performed by using data coming from the permanent Italian seismic network run by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the "Cut And Paste" (CAP) method based on broadband waveform inversion. Focal mechanisms, source depths and moment magnitudes are determined through a grid search technique. By allowing time shifts between synthetics and observed data the CAP method reduces dependence of the solution on the assumed velocity model and on earthquake location. We computed seismic moment tensors for 312 earthquakes having local magnitude in the range between 2.7 and 5.9. The CAP method has made possible to considerably expand the database of focal mechanisms from waveform analysis in the lowest magnitude range (i.e. in the neighborhood of magnitude 3) without overlooking the reliability of results. The obtained focal mechanisms generally show NW–SE striking focal planes in agreement with mapped faults in the region. Comparisons with the already published solutions and with seismological and geological information available allowed us to proper interpret the moment tensor solutions in the frame of the seismic sequence evolution and also to furnish additional information about less energetic seismic phases. Focal data were inverted to obtain the seismogenic stress in the study area. Results are compatible with the major tectonic domain. We also obtained a relation between moment and local magnitude suitable for the area and for the available magnitude range.

1. Introduction

On April 6, 2009 (3:32 AM local time) a moderate magnitude earthquake ($M_w = 6.2$) struck central Italy near the city of L'Aquila. It was felt throughout Italy and 308 persons were killed while over 65,000 were left homeless (Akinci and Malagnini, 2009). The mainshock was followed by thousands of aftershocks detected and located by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) also using a portable seismic network installed a few hours after the earthquake (Margheriti et al., 2010). The portable seismographs were deployed to capture near-source and small aftershocks and to ensure the availability of high quality scientific datasets for studies related to hazard, seismotectonics and earthquake physics. Fig. 1 shows the high seismic activity of the study region as testified by the background seismicity recorded in the last 30 years by the INGV seismic network (http://istituto.ingv.it/l-ingv/archivi-e-banche-dati/). The location and geometry of the fault systems that generated the L'Aquila sequence have been investigated by Chiarabba et al. (2009) and Chiaraluce et al. (2011) analyzing the aftershock distribution. Chiarabba et al. (2009) identified a quite complex NW-trending extensional system of about 40 km in length while the fault segment ruptured during the mainshock had a length of approximately 20 km and dips at about 45° towards SW. The authors also pointed out that the aftershock distribution coincides with the Paganica–San Demetrio fault which presented surface fractures mapped after the mainshock (EMERGEO Working Group, 2009, 2010). Several authors have reported complexity of the L'Aquila earthquake (see e.g. D'Amico et al., 2010a and references therein) showing that it ruptured towards the south–southeast with respect to the epicenter. D'Amico et al. (2010a) also reported that the spatial extent of the rupture image correlates well with a post-seismic survey of damage in the region.

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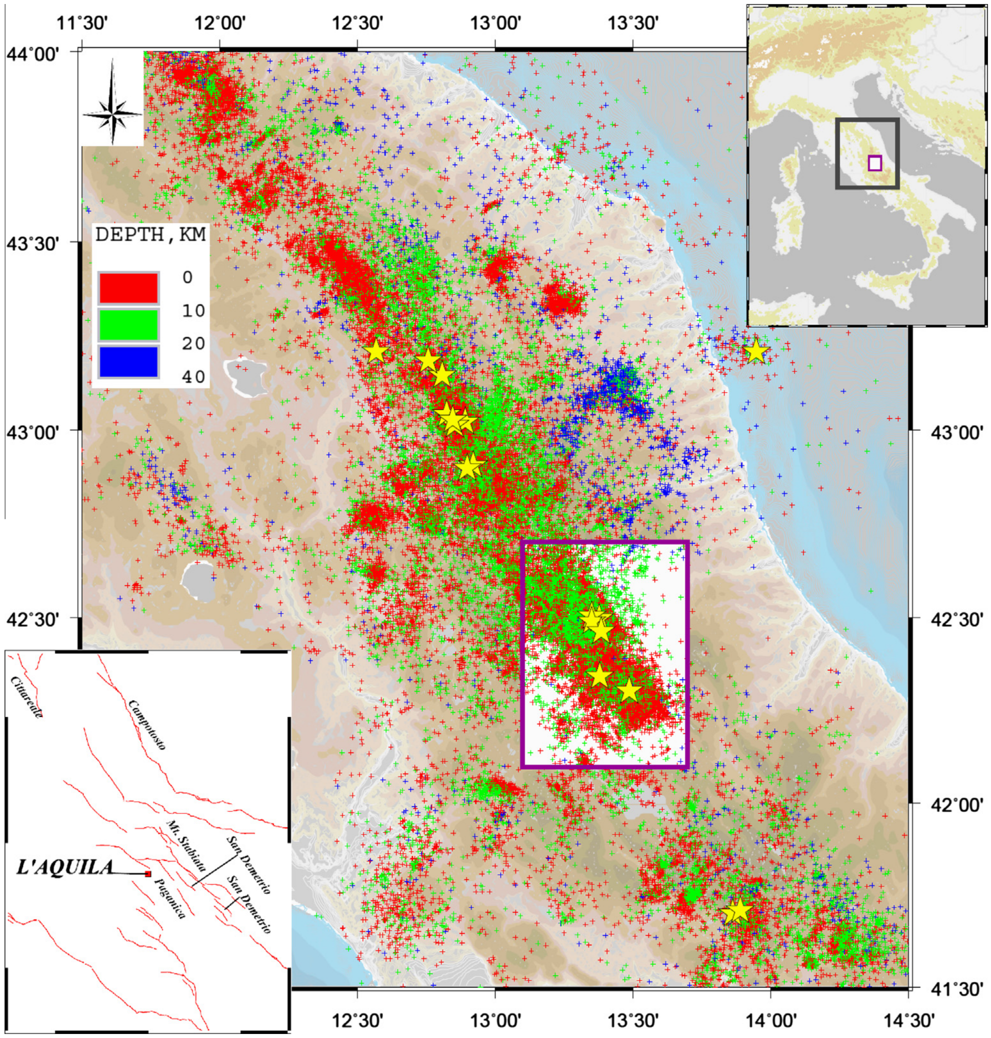

Fig. 1. Map of the study region showing the background seismicity. The distribution of the epicenters of the seismic events (1981–2011) as a function of depth is reported. Yellow stars represent events having moment magnitude greater than five. The area of the L'Aquila seismic sequence is indicated by white background. The lower-left inset shows the main faults in the region. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The main goal of this paper is to obtain a detailed catalog of moment tensor solutions of small and moderate aftershocks of the L'Aquila seismic sequence by performing broadband waveform inversion. Thanks to the most recent developments of the instrumental network operating in the area, and the application of techniques performing waveform inversion of low-magnitude earthquakes (D'Amico et al., 2008, 2010b, 2011, 2012; D'Amico and Galea, 2011; Stich et al., 2003; Zhu et al., 2006) the conditions were suitable for analyzing a great number of data and computing the moment tensor solutions also for minor (e.g. $M < 3.5$) earthquakes not often included into the catalogs. Using the resulting moment tensor solutions we were able to compute the regional stress tensor in the study area and in selected sub-volumes contributing to a better knowledge of seismogenic processes. Modeling regional waveforms provides good constrain in determining accurately source mechanism, moment magnitude, and depth. Langston (1981) showed that it is possible to discriminate among fault types using the relative amplitude of P, SH, and SV waveforms. In the last decades many authors used both body waves (Dreger and Helmberger, 1993; Fan and Wallace, 1991) and surface waves at different periods (Herrmann, 2008; Ritsema and Lay, 1993; Romanowicz et al., 1993; Thio and Kanamori, 1995) in order to obtain the moment tensor solutions. Zhao and Helmberger (1994), and later Zhu and Helmberger (1996), proposed a method, known in literature as "Cut And Paste" (CAP), that separates the entire records in body and surface waves and model them with differential time shifts. In doing so this method desensitizes the timing between the principal crustal arrivals, hence accurate source estimates can be achieved also with the use of imperfect Green's functions.

In the present paper we applied the CAP method (Tan et al., 2006; Zhu and Helmberger, 1996) to invert the broadband waveforms of earthquakes with local magnitude greater than 2.7 occurred between April 2009 and March 2010. The obtained focal solutions are also compared with the Regional Centroid Moment Tensor (RCMT; www.bo.ingv.it/RCMT, Pondrelli et al., 2010) and Time Domain Moment Tensor (TDMT; http://earthquake.rm.ingv.it/tdmt.php, Scognamiglio et al., 2010) solutions available in the official databases for critical evaluation of results coming from application of different techniques. We also compare our results and interpret them with the findings of several studies conducted in the area (Boncio et al., 2004, 2010; Chiaraluce et al., 2011). Moreover, we obtain regional stress tensor by using earthquake focal mechanisms computed in this study and we derived a M_w–M_l relationship suitable for the area. Systematic study of small events, through the determination of moment tensor and fo-